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NWC TP 4720

EVALUATION OF EXPLOSIVES SIMULTANEITY TESTS

by

URS Research Company
for the
Systems Development Department

ABSTRACT. This report presents the results and evaluation of two full-scale explosives tests conducted at NWC, China Lake, as part of the explosives hazards studies being carried out by the Armed Services Explosives Safety Board (ASESB). The tests were run to investigate the validity of the simultaneity provision in military quantity-distance regulations governing ammunition storage in the vicinity of inhabited buildings or facilities. The first (control) test involved the detonation of a single 10,000-pound hemispherical charge of TNT placed in the center of a donor structure constructed to storage-bay standards, with the charge located at the 865-foot regulation distance from a test house. A barricade was placed between the house and the charge. The second test was identical to the first except that two 5,000-pound hemispherical charges were used, each of which was placed in the center of an individual donor-bay compartment and separated by a specially constructed nonpropagation steel-reinforced concrete dividing wall. The two charges were detonated at a programmed time delay of approximately 20 msec, the nominal time interval noted between propagations in previous tests.

Based on test results, there is no significant difference in the damage to be expected from the detonation of a fixed weight of explosives at the regulation distance from a barricaded inhabited building, either as a single charge or as two equal charges detonated 20 msec apart. Gage lines on opposite sides of the detonation did not register any significant difference between air blast parameters on the barricaded versus the unbarricaded side.

NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA * MAY 1969

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FOREWORD

This report describes the results of two full-scale tests involving the detonation of 10,000 pounds of TNT in two differing configurations. In each case, the explosive charge (donor) was located at the minimum distance from an inhabited building permitted by existing DoD regulations for the total charge weight of 10,000 pounds. The tests, which were conducted in April 1967 and April 1968 by the Naval Weapons Center, were funded by the Army, Navy, Air Force, Defense Atomic Support Agency, and the National Aeronautics Space Administration under the auspices of the ASESB.

This report is the edited version of the material prepared by the URS Research Company, Burlingame, California, under a contract that called for the reduction, analysis, and documentation of data furnished by NWC.

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INTRODUCTION

In general, military safety regulations governing quantity-distance requirements for high explosives facilities (Ref. 1) stipulate that if explosives stored on each side of a substantial dividing wall* are prevented from detonating "simultaneously,"* the quantities separated by the dividing wall need not be added for quantity-distance computations. The regulations of the different military departments vary, with some authorizing a net quantity of as much as 5,000 pounds of high explosives to be placed on either side of a standard 12-inch-thick reinforced concrete dividing wall. In addition, the regulations allow changes in the stated quantity-distance relationship depending on the presence or absence of an effective barricade.* That is, minimum stated intermagazine, operating building (intraline), inhabited building, and railroad or highway distances are reduced by as much as a factor of two if the stored explosives are barricaded.

During recent months several agencies and investigators have questioned the validity of the above stated principle. In work performed by the Naval Weapons Center (Ref. 2), propagation of an explosion to acceptors through a standard dividing wall occurred with as small a quantity as 400 pounds of HE. These propagated explosions occurred at time intervals of 3 to 20 msec after detonation of the donor charge. Follow-on theoretical work, sponsored by the ASESB (Ref. 3), and small-scale HE tests, by URS Systems Corporation (Ref. 4) further indicated that, even with the two detonations occurring at scaled times much greater than 20 msec apart, the shock waves from the donor and acceptor charges combine, and the resulting shock wave is equivalent to that from a charge equal to the combined weight of the donor and acceptor charges at distances starting far short of the regulation barricaded inhabited building distance.

To verify the findings of the theoretical studies and the small-charge tests, two full-scale barricaded house tests were conducted at NWC, China Lake. Each test consisted of detonating 10,000 pounds of TNT placed in a storage bay at the specified 865-foot distance from a two-story test house using two gage arrays (A and B, Fig. 1) to obtain comparison data on overpressure and positive-phase impulse, and a third gage array (C) to obtain auxiliary data. One 10,000-pound charge was used in the first test, conducted in April 1967; two 5,000-pound charges were used in the second test, conducted in April 1968.

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*The terms "substantial dividing wall," "simultaneously," and "effective barricade" have specific connotations in explosive safety and are explicitly defined in Ref. 1.

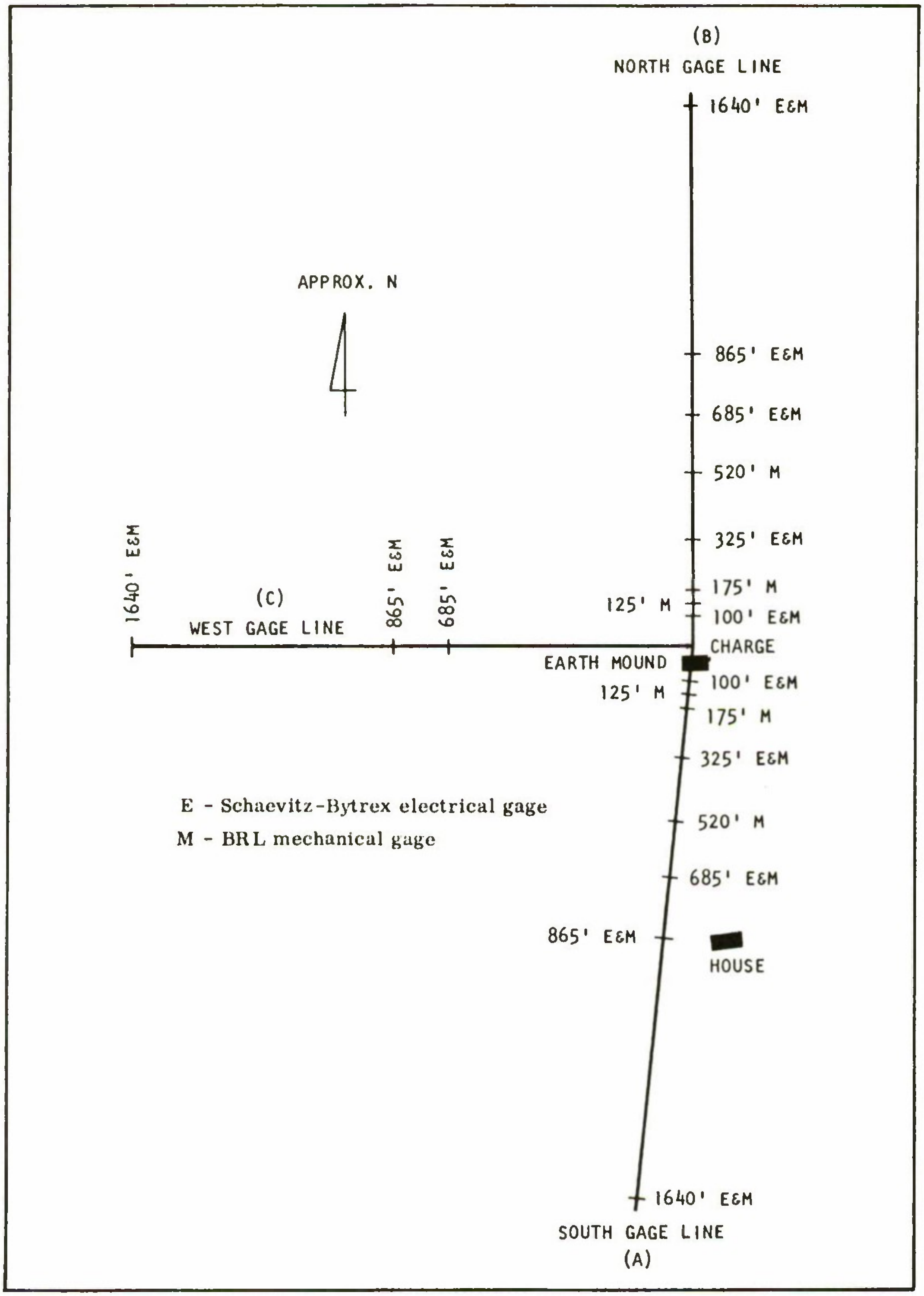


FIG. 1. Layout of Test Site. Gage distances measured from center of charge, house 865 feet from edge of storage bay.

SUMMARY OF RESULTS

Based on the full-scale tests, it appears that there is no validity to the concept that a 10-foot-high earth mound barricade placed near the explosive charge will increase the safety of an inhabited building at the regulation distance (see Evaluation of Test Results, page 18).

Comparison of data measured along the barricaded (A) and unbarricaded (B) gage lines in the two tests indicates that, at the allowable inhabited building distance, there is essentially no difference between the overpressure levels generated by the detonation of a single 10,000-pound charge and those generated by two 5,000-pound charges ignited approximately 20 msec apart. On the other hand, the data show that the 10,000-pound detonation produced higher positive-phase impulse forces than did the spaced detonation of two 5,000-pound charges.

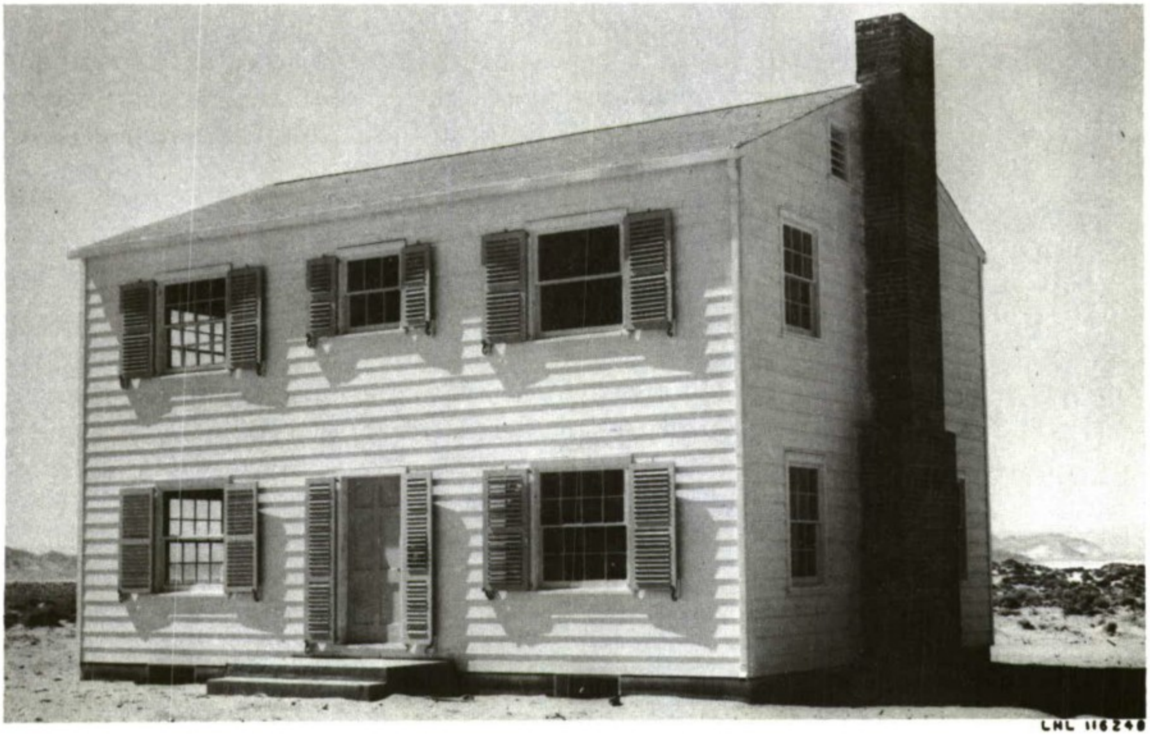
TEST LAYOUT AND INSTRUMENTATION

TEST FACILITIES

The facilities used for the tests consisted of a conventional two-story frame house, a standard earth barricade, a concrete explosives bay, and 10,000 pounds of TNT arranged as shown in Fig. 1. The front of the house faced the storage bay at ground zero and was 865 feet from the near edge of the bay.

Test House

The house, which was constructed basically in accordance with the Office, Chief of Engineers, D/A Drawing 60-08-45, revised 23 July 1959, was 33 feet 4 inches long by 24 feet 8 inches wide, with full basement and gabled roof (Fig. 2). There were four rooms on each floor, with a brick fireplace in the living room. The walls were plaster but, to reduce cost, the finish coat was eliminated, as were plumbing, electrical, and heating systems. The two large window panes in the front of the house were 1/8-inch thick, the rest of the windows were 3/32-inch thick, and there was a 10-foot 2-inch spacing between the side windows in the kitchen and dining room. For roof sheathing, 3/4-inch plywood was used instead of lumber, and ash and fir 2x4s were used instead of pine for wall studding.



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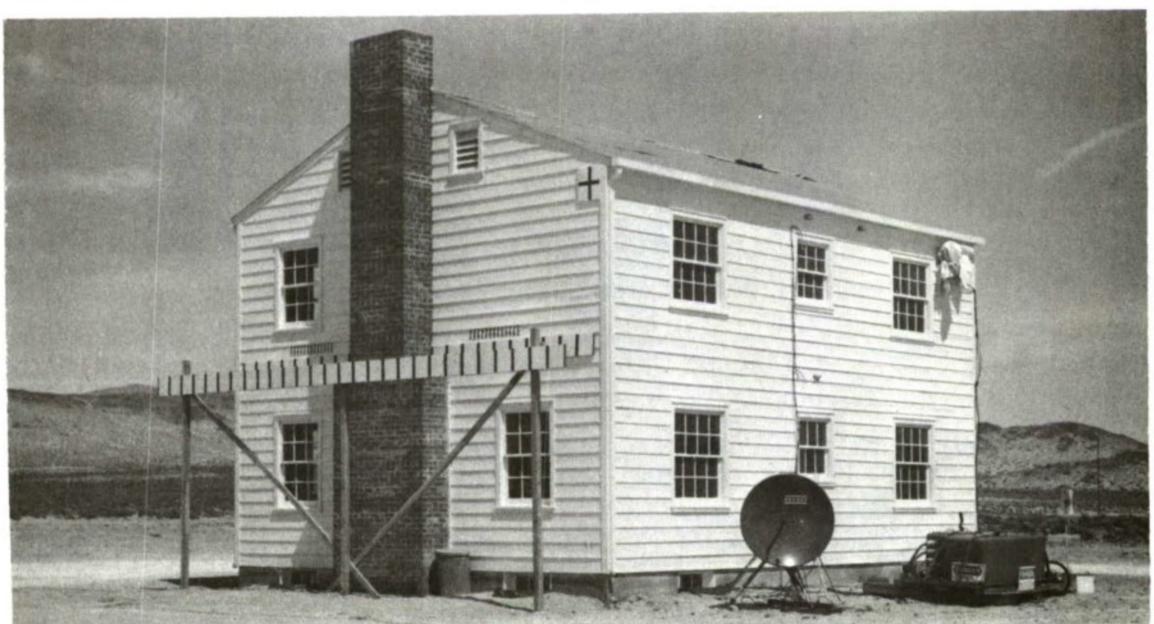

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FIG. 2. Exterior Views of Test House.

Donor Structure (Storage Bay)

The donor structure had a 20-foot-square floor area with a 10-foot-high, 20-foot-long wall erected on each of the two sides parallel to the common center-line of the house and the donor structure. As required by specifications for certain typical bays or cubicles, the floor was 9 inches thick, and the walls were constructed of 12-inch-thick concrete having a compressive strength of at least 2,550 psi, with both bases of each wall being reinforced vertically and horizontally with standard No. 4 bars placed 12 inches on center.

The donor structure for the second test, constructed as above, had 20-foot-long side walls and a floor space of 17 feet by 20 feet for each donor. The two donors were separated by a specially designed nonpropagation wall 10 feet high, 20 feet long, and 4 feet thick (Fig. 3 and 4).

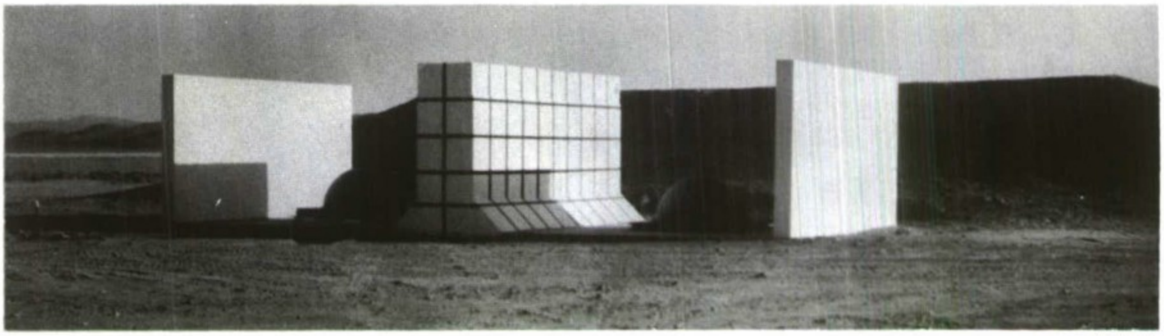

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FIG. 3. Two 5,000-Pound Charges in Place for Test No. 2.

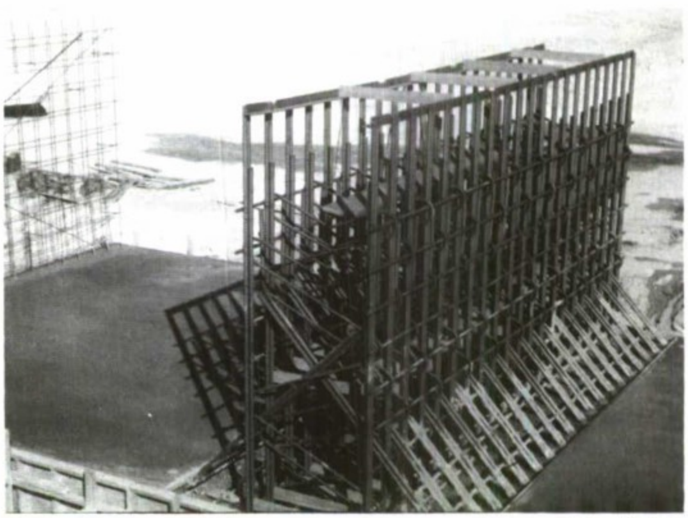

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FIG. 4. Inside Construction of Center Dividing Wall.

Barricade

The earth barricade was located between the house and the explosives bay with its toe 4 feet from the edge of the concrete floor slab. It was 10 feet high, 3 feet wide at the top, and extended 10 feet beyond the outside walls on either side of the donor structure. The slope of the barricade was 2:1, making it 82 feet long and 43 feet wide at ground level for the first test and 104 feet long and 43 feet wide at ground level for the second test. The material used was sandy earth available in the area, with stones heavier than 10 pounds or larger than 6 inches in diameter being removed overall and stones over 1 inch in diameter being removed from the surface of the finished mound.

INSTRUMENTATION

The three gage lines were instrumented with 13 electrical piezoresistance Schaevitz-Bytrex gages and 19 Ballistic Research Laboratory (BRL) mechanical air-blast pressure gages to measure peak overpressure and positive-phase impulse. In addition, two piezoresistance gages were located on the house, and two were placed inside the house.

Optical instrumentation included 10 motion-picture cameras, 16mm, 35mm, or 70mm operated at different frame rates between 24 and 10,000 fr/sec, to record fragment travel and house response to blast overpressure. In addition, several still cameras were used to take documentary photographs inside and outside the house, before and after each test.

Other instrumentation included equipment for receiving coded timing signals and equipment for recording meteorological phenomena.

FRAGMENT COUNT

In addition to measuring peak blast overpressure and positive-phase impulse, a fragment survey was made after each test. This was done by searching 12 areas staked out before the tests. Three search areas each were located 685, 865, and 1,640 feet to the north, south, east, and west of the donor structure. The first distance corresponds to the distance allowed by the regulations for the storage of 5,000 pounds of HE in the vicinity of a barricaded inhabited building, the second represents the distance allowed for the storage of 10,000 pounds of HE near a barricaded inhabited building, and the third is the distance at which it is predicted that a 0.5-psi overpressure will occur as the result of the detonation of 10,000 pounds of HE.

TEST PROCEDURES AND RESULTS

TEST NO. 1

The first test was a control test in which a single 10,000-pound charge, built of cast blocks of TNT stacked to approximate a hemisphere (Fig. 5), was placed in the center of the 20-foot-square donor bay and detonated. The bay was completely destroyed by the blast (Fig. 6), and a crater about 38 feet in diameter by 9 feet deep was formed.

After the blast, all the front windows of the house, except the small one above the front door, were completely removed (Fig. 7). The door was torn off its hinges and blown into the front hall, and all basement windows forward of the centerline of the house were blown in. Figure 8 is a view of the east and south sides of the house. Note the window damage on the east (right side) wall and that only one pane of glass on the back (south) wall was broken. This pane was broken by a wooden fragment from the front window, rather than by the blast. There were also chimney damages, some of which are indicated by the chalk marks in Fig. 9.

Large quantities of glass and pieces of window frames and shades were scattered throughout the interior of the house (Fig. 10-13), and some plaster cracking was visible in several of the rooms. Very little furniture movement or damage occurred and, as shown in Fig. 13, even the lampshades were only slightly jarred. None of the wall-mounted mirrors was damaged.

FIG. 5. Configuration of 10,000-Pound Charge for Test No. 1.

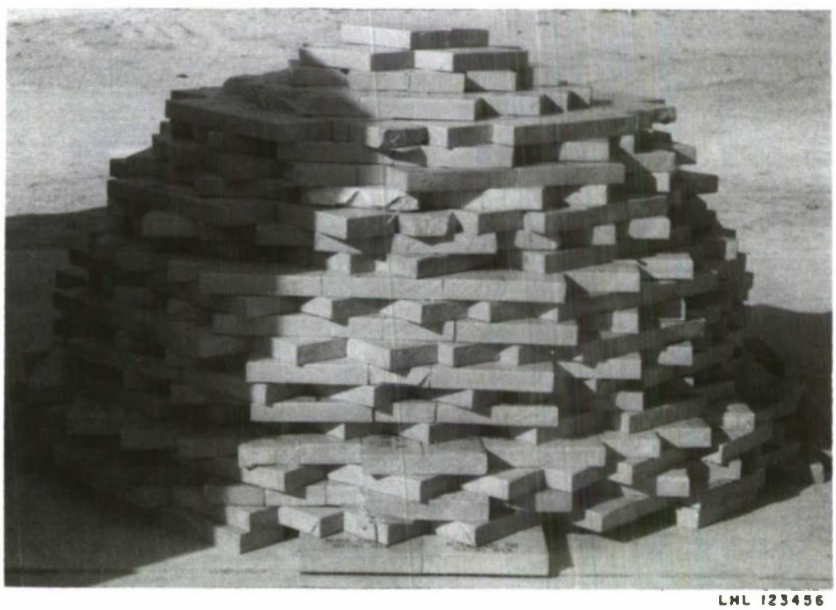

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FIG. 6. Crater Formed by Detonation of Single 10,000-Pound Charge.

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FIG. 7. Front and West Sides of Test House
After Test No. 1.

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FIG. 8. Back and East Sides of Test House
After Test No. 1.

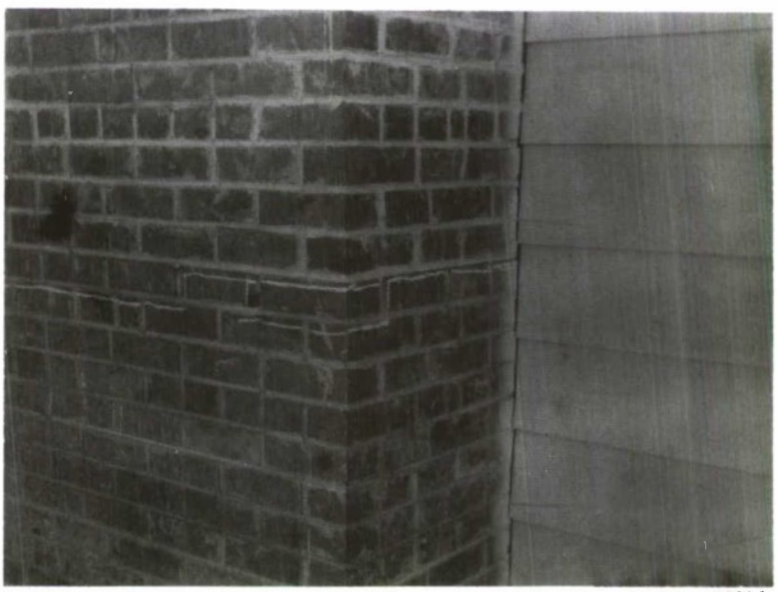

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FIG. 9. Chimney Damage Resulting From Detonation
of Single 10,000-Pound Charge.

FIG. 10. Damage to Upstairs Northeast Bedroom, Test No. 1.

FIG. 11. Damage to Upstairs West Bedroom, Test No. 1.

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FIG. 12. Dining Room Damage, Test No. 1.

LNL 123555

FIG. 13. Living Room Damage, Test No. 1.

TEST No. 2

The setup for this test was like that used in Test No. 1, except that two 5,000-pound cast hemispherical charges of TNT, separated by a specially designed heavily reinforced substantial dividing wall (see Fig. 3), were placed in the donor structure and detonated 20 msec apart. Most of the donor structure was destroyed, the special wall between the charges was damaged, and craters approximately 10 feet deep and 20 feet in diameter were formed (Fig. 14).

Damage to the house, which had been restored after the first test, was similar to that incurred from the single 10,000-pound blast. Note in Fig. 15 that damage to the front windows was slightly more extensive than in the first test and that a shutter at the upper left window was torn loose; whereas, no shutters were torn loose in the first test (compare Fig. 15 with Fig. 7). Figure 16 shows that window damage was substantially greater after the second test than after the first (see Fig. 8), and all windows forward of the centerline of the house were damaged.

Damage to the chimney (Fig. 17) was also more severe after the second test than after the first. Cracks were larger, more spalling occurred, and a large portion of the chimney was separated from the wall by an inch or more.

Inside the house, plaster cracking was also generally more severe. The door between the dining room and kitchen was badly damaged (Fig. 18), and the rafter damage, shown in Fig. 19, was apparently the most significant damage to a structural element in the house from either test.

Damage to the interior of the upstairs was about the same as that observed in Test No. 1, except that much of the flying glass was intercepted by styrofoam glass-traps and never reached the floor. Again, no mirrors were cracked and no furniture was moved. Damage to the downstairs interior was also comparable to that in the first test, with neither flying glass, pieces of window frame, nor the blast itself significantly disturbing furniture position (Fig. 20).

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FIG. 14. Views of Dividing Wall and Craters After Programmed Detonation of Two 5,000-Pound Charges, Test No. 2.

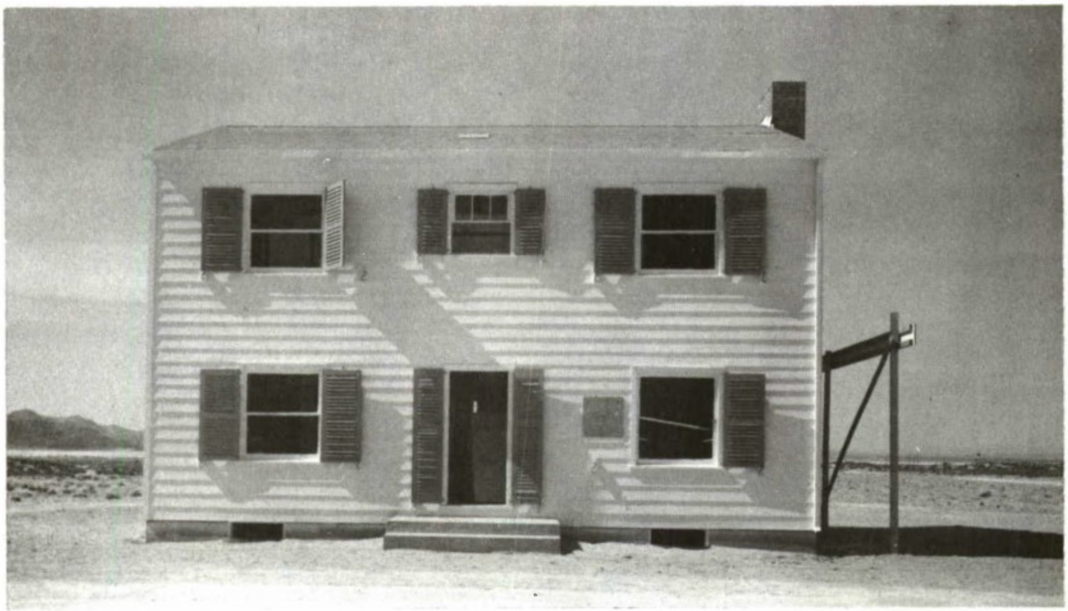

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FIG. 15. Front of House After Test No. 2.

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FIG. 16. Back and East Sides of House After Test No. 2.

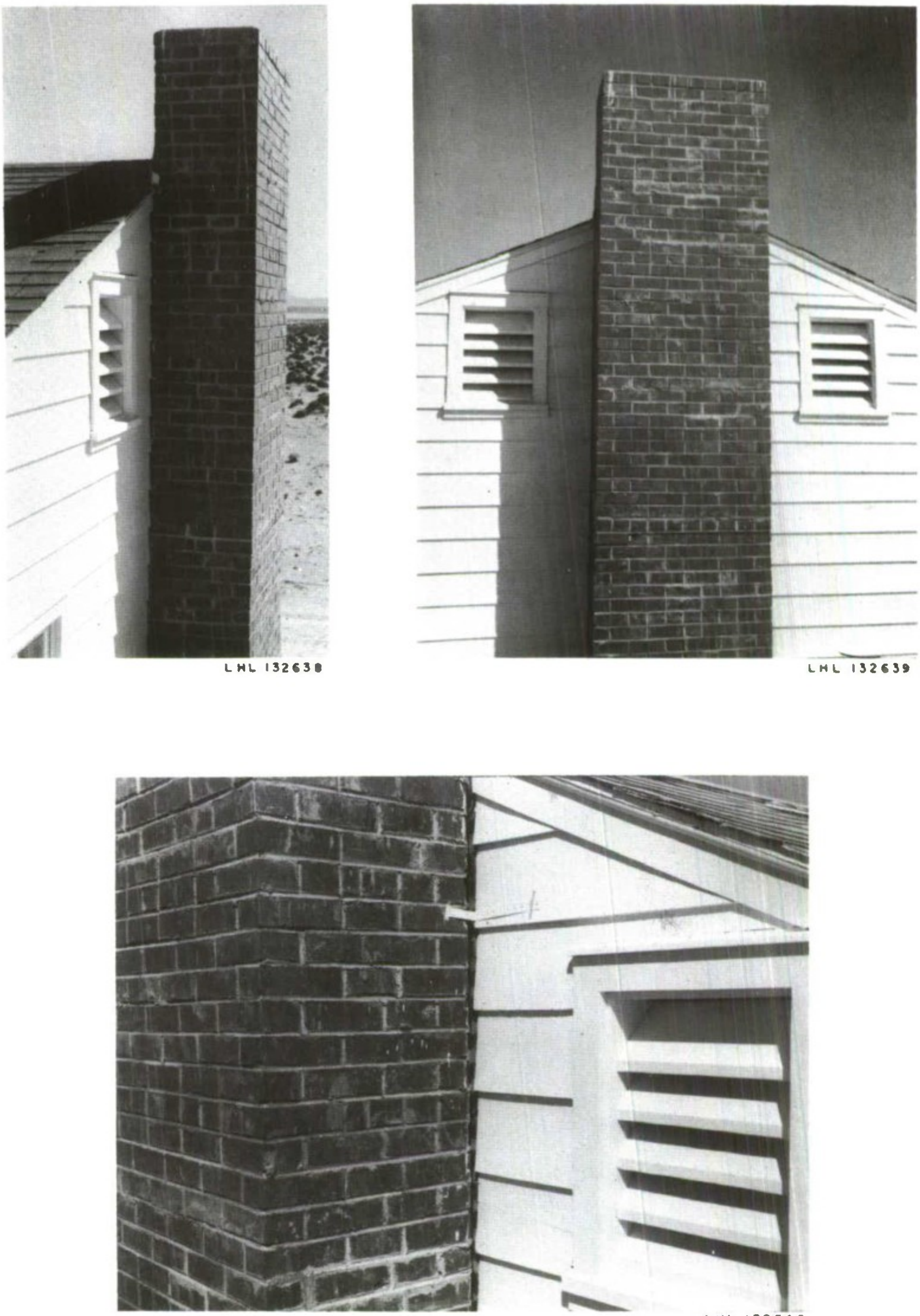

FIG. 17. Views of Chimney Damage, Test No. 2.

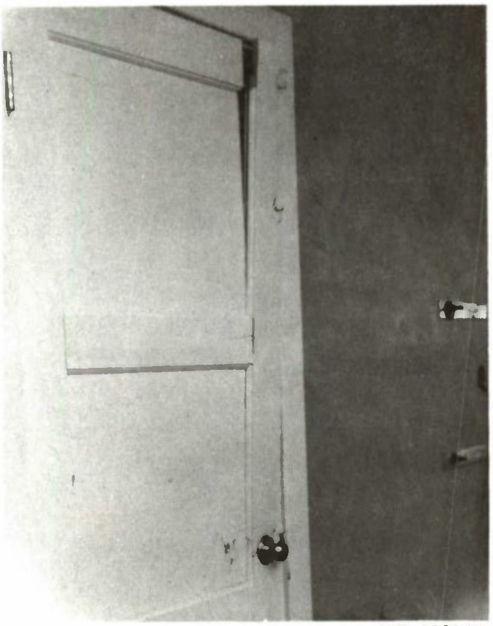

FIG. 18. Door Between Dining Room and Kitchen After Test No. 2.

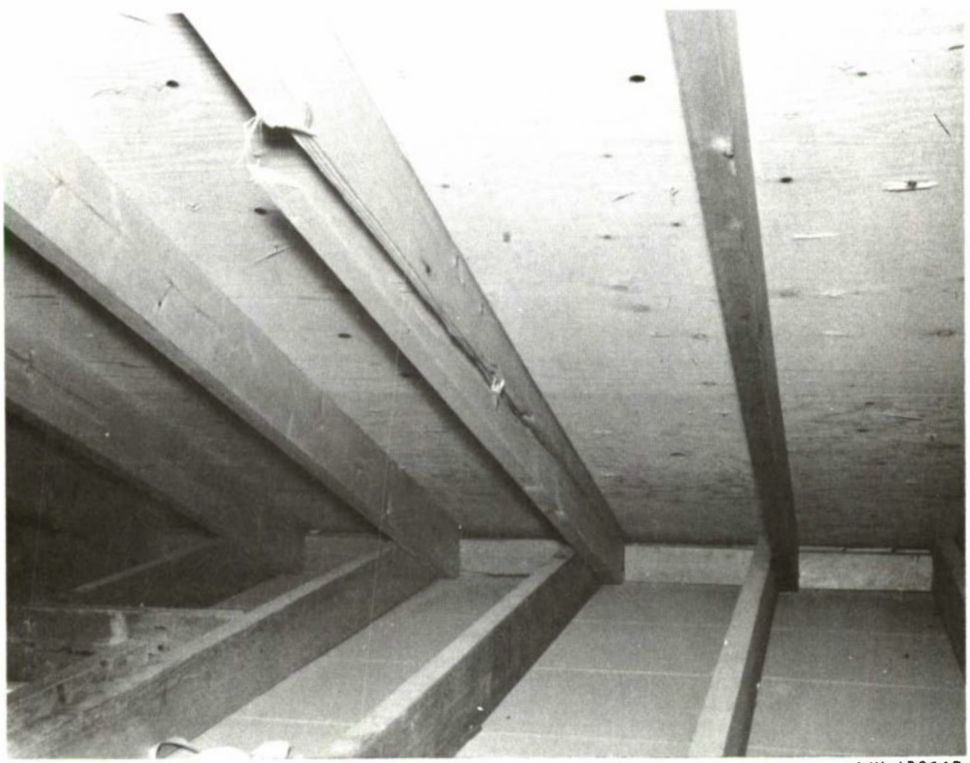

FIG. 19. Rafter Broken in Test No. 2.

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FIG. 20. Views of Living Room Damage, Test No. 2.

EVALUATION OF TEST RESULTS

The peak overpressure and positive-phase impulse data obtained in the two tests are presented in Table 1. Note that the peak overpressure data from the BRL mechanical gages are generally in good agreement with the data from the Bytrex electrical gages.

OVERPRESSURE DATA

The peak overpressures measured during the tests are plotted as a function of distance in Fig. 21 and 22, and the peak overpressure data recorded for the B and A gage arrays in both tests are shown in Fig. 23 and 24, along with two curves taken from Ref. 5, representing the anticipated TNT falloff curve for the detonation of 5,000 and 10,000 pounds of explosives. In Fig. 23, the data from the unbarricaded array (B) for both tests fit the reference curve for the detonation of 10,000 pounds of HE, but not for the 5,000-pound quantity at any ground range. In Fig. 24, for the delayed ignition of two 5,000-pound charges, Test No. 2, the peak overpressure data recorded by the barricaded gages (A) from the two stations closest to ground zero fit the falloff curve for the 5,000-pound charge, while the data from the remaining stations fit along the 10,000-pound charge falloff curve. Figure 25 shows why this should occur.

At the two closest ground ranges along the barricaded leg (Fig. 25a and b) the two shocks have not coalesced, and the maximum peak overpressure is at the shock front of the first pulse and is, in fact, from a single 5,000-pound charge detonation. At the third station from ground zero, located at approximately 180 feet from the charge (Fig. 25c), the two shocks have started to coalesce, and the maximum peak overpressure is at the second peak. Of course, the shock front (first peak) is still due to the explosion of one 5,000-pound charge and, consequently, the peak overpressure there still falls (within the experimental limits of error) on the anticipated 5,000-pound charge falloff curve (see this point plotted in Fig. 24), while the second peak corresponds very nearly to that from the explosion of a 10,000-pound charge. Figure 25d of the sequence shows the pulse at the next station after the second shock front has caught the first, and now the shock fronts from the two pulses coincide at a value definitely equivalent to that from a single 10,000-pound charge detonation. Thus, along the barricaded leg at a distance corresponding to somewhere between a K factor (reduced distance, or $d/w^{1/3}$) of 7 and 15, the overpressure data from the two 5,000-pound charges with a programmed delay of approximately 20 msec between ignitions cannot be distinguished from the reference curve. From these

data, it is clear that, in reference to the damage parameter of peak overpressure, there is essentially no difference between the detonation of a single 10,000-pound charge and the programmed delayed detonation of two 5,000-pound charges, at the prescribed barricaded inhabited building distance for 10,000 pounds of HE.

POSITIVE-PHASE IMPULSE DATA

Figure 26, which is a plot of the positive-phase impulse data from the unbarricaded gage leg for the two tests plus curves from Ref. 5, shows that the electrical gage data from the detonation of the single 10,000-pound charge are a very good fit to the 10,000-pound reference curve, with the exception of the station closest to the charge, where it falls considerably higher. Although the electrical gage data from Test No. 2 are in short supply, the points available fall below those for Test No. 1. Along the unbarricaded gage leg, then, the Test No. 2 data are at the level expected from the detonation of a charge slightly under 7,000 pounds versus 10,000 pounds for the Test No. 1 data. The mechanical gage data along the unbarricaded leg, however, indicate a much smaller positive-phase impulse difference between the two tests. When the electrical and mechanical gage data on the unbarricaded side are averaged for each test and then compared, the disparity between the two tests is a yield of 8,500 pounds of TNT versus a yield of 10,000 pounds, excluding events at the closest station, which seem to disagree radically with all the other stations. The conclusion is that there is some effect on positive-phase impulse when the 10,000 pounds of HE is ignited as two charges with a 20 msec delay, rather than when detonated all in a single charge.

Figure 27 shows the graphed positive-phase impulse data from the A and B gages for Test No. 2. The electrical gage data for the barricaded leg fall between a 7,000- and a 10,000-pound yield over the entire range while, along the unbarricaded leg, the data fall between a 5,000- and a 7,000-pound yield in the vicinity of the barricaded inhabited building distance. However, one data point close-in falls considerably above that expected from the detonation of 10,000 pounds of HE. The average of the mechanical gage data falls only slightly below that for 10,000 pounds of HE, ranging from a minimum slightly above a 7,000-pound yield to a maximum of more than a 10,000-pound yield at the station just before, and the one just beyond, the ground range corresponding to the barricaded inhabited building distance. The mechanical gage data taken along the unbarricaded array shows a slightly greater range than for the barricaded array and, in the vicinity of the barricaded inhabited building distance, the average is midway between the 7,000- and the 10,000-pound yield levels.

When the positive-phase impulse data from both types of gages on each of the two legs for each test are averaged, the data from the unbarricaded leg are consistently about 10% lower than the data from the barricaded leg for all stations except the one closest to the charge.

Due to the power failure to the barricaded leg in Test No. 1, no positive-phase data could be obtained along that gage line for the single 10,000-pound charge detonation. Hence, no further positive-phase impulse comparisons could be made.

FRAGMENT SEARCH RESULTS

Figure 28 shows the distribution of concrete and steel pieces exceeding either 6 inches in diameter or 4 feet in length that were found after Test No. 1 in the 200-foot-radius search area centered at the house on the barricaded side and a like search area centered at the 865-foot station on the unbarricaded side. It is interesting to note that 17 such fragments were found in the area on the barricaded side, and only three were found in the corresponding area along the unbarricaded side. No fragments were found in the other search areas after this test. In Test No. 2, no fragments were found beyond 600 feet on either the barricaded or unbarricaded side. However, on the unbarricaded west leg (C in Fig. 1), to the side of the charge, approximately 130 fragments were found in a 200-foot-radius circle centered at the 865-foot distance.

HOUSE DAMAGE

Probably the most important index of house damage pertinent to this problem would be the cost of repairs. The estimated repair cost after the first test was $2,095 (8.5% of the initial $24,604 estimated cost of the house), and the estimated repair cost after the second test was $4,060 (16.5% of the initial estimated cost of the house), indicating that considerably more house damage occurred during the second test. However, it should be noted that the house was not an innocent structure in the second test; i.e., it had already undergone one test and was a year older. Hidden damage from the first test and natural aging may have caused the house to be weaker during the second test. Also, since there were no plumbing, heating, or electrical systems in the house and the interior walls were not finished, the final cost of repairing a truly habitable building could be either slightly higher or lower in terms of the percentage of the replacement cost of the house.

TABLE 1. Summary of Test Data

Test No.	Test Type	Parameter Measured	Gage Line	Nominal Distance From Ground Zero (ft)							
				100	125	175	325	520	685	865	1640
1	10,000-lb TNT Hemisphere in Storage Bay	Peak Overpressure	A(M)	45.3	17.4	14.7	4.57	2.22	1.33	0.780[4]	BD
			A(E)	1	NG	NG	1	NG	1	0.862[2]	BD
			B(M)	47.4	26.4	NG	5.26	1.96	1.72	1.31	0.545
			B(E)	58.9	NG	NG	4.95	NG	1.59	1.12	0.463
			C(M)	NG	NG	NG	NG	NG	1.75	1.29	0.539
			C(E)	NG	NG	NG	NG	NG	1.84	NG	0.547
		Positive-Phase Impulse	B(M)	470	248	NG	88.9	63.1	52.1	55.2	25.8
			B(E)	366	NG	NG	109	NG	51.0	39.2	20.1
			C(M)	NG	NG	NG	NG	NG	59.2	BD	21.1
			C(E)	NG	NG	NG	NG	NG	65.0	NG	25.1
2	2-5000-lb TNT Hemispheres in Divided Storage Bay Detonated ~ 20 msec apart	Peak Overpressure	A(M)	26.5[3]	16.1[3]	12.6[3]	4.87	2.27	BD	BD	0.513
			A(E)	36.1[3]	NG	NG	5.17	NG	1.58	1.10	0.456
			B(M)	44.9[3]	28.4[3]	BD	BD	2.20	1.56	1.26	0.476
			B(E)	53.1[3]	NG	NG	BD	NG	1.56	NG	0.585
			C(M)	NG	NG	NG	NG	NG	1.62[3]	1.25[3]	0.718
			C(E)	NG	NG	NG	NG	NG	1.63[3]	BD	0.636
		Positive-Phase Impulse	A(M)	241	257	162	106	59.3	BD	BD	24.9
			A(E)	242	NG	NG	98.8	NG	46.4	37.2	17.6
			B(M)	458	233	BD	92.9	56.4	44.4	BD	23.9
			B(E)	370	NG	NG	BD	NG	38.9	NG	14.7
			C(M)	NG	NG	NG	NG	NG	56.4	50.7	20.2
			C(E)	NG	NG	NG	NG	NG	61.7	NG	23.8

Notes:

1. Lack of power prevented acquisition of any data other than peak overpressure from the mechanical gages.
2. Calculated from reflected overpressure measured on front of house (measured peak reflected overpressure 1.77 psi). A roof gage reading of 1.42 psi was also obtained on this test.
3. Double peak, higher peak measured
4. Suspect data point

NG = No gage
BD = Bad data
M = Mechanical
E = Electrical

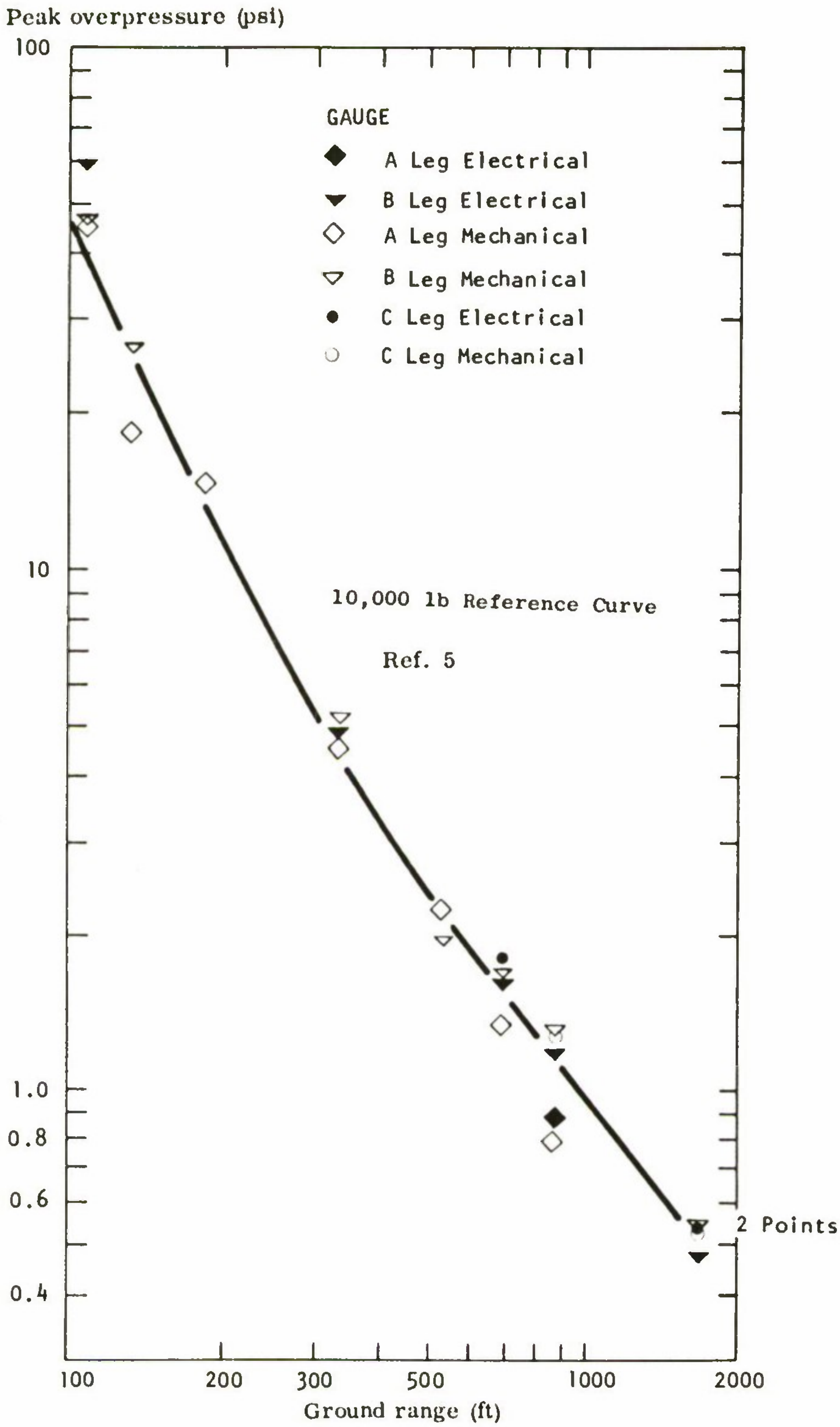

FIG. 21. Peak Overpressure Versus Distance, Test No. 1.

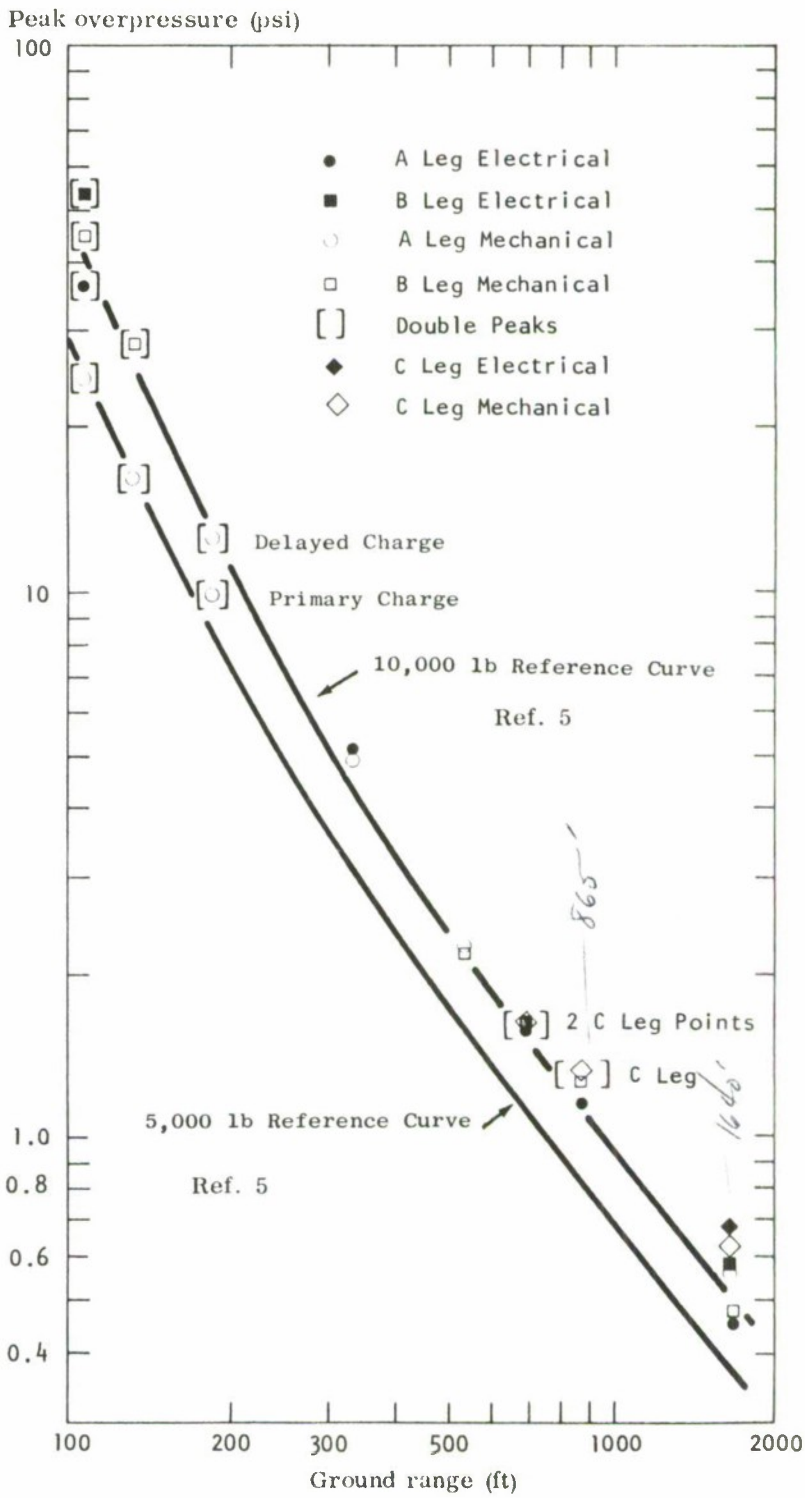

FIG. 22. Peak Overpressure Versus Distance, Test No. 2.

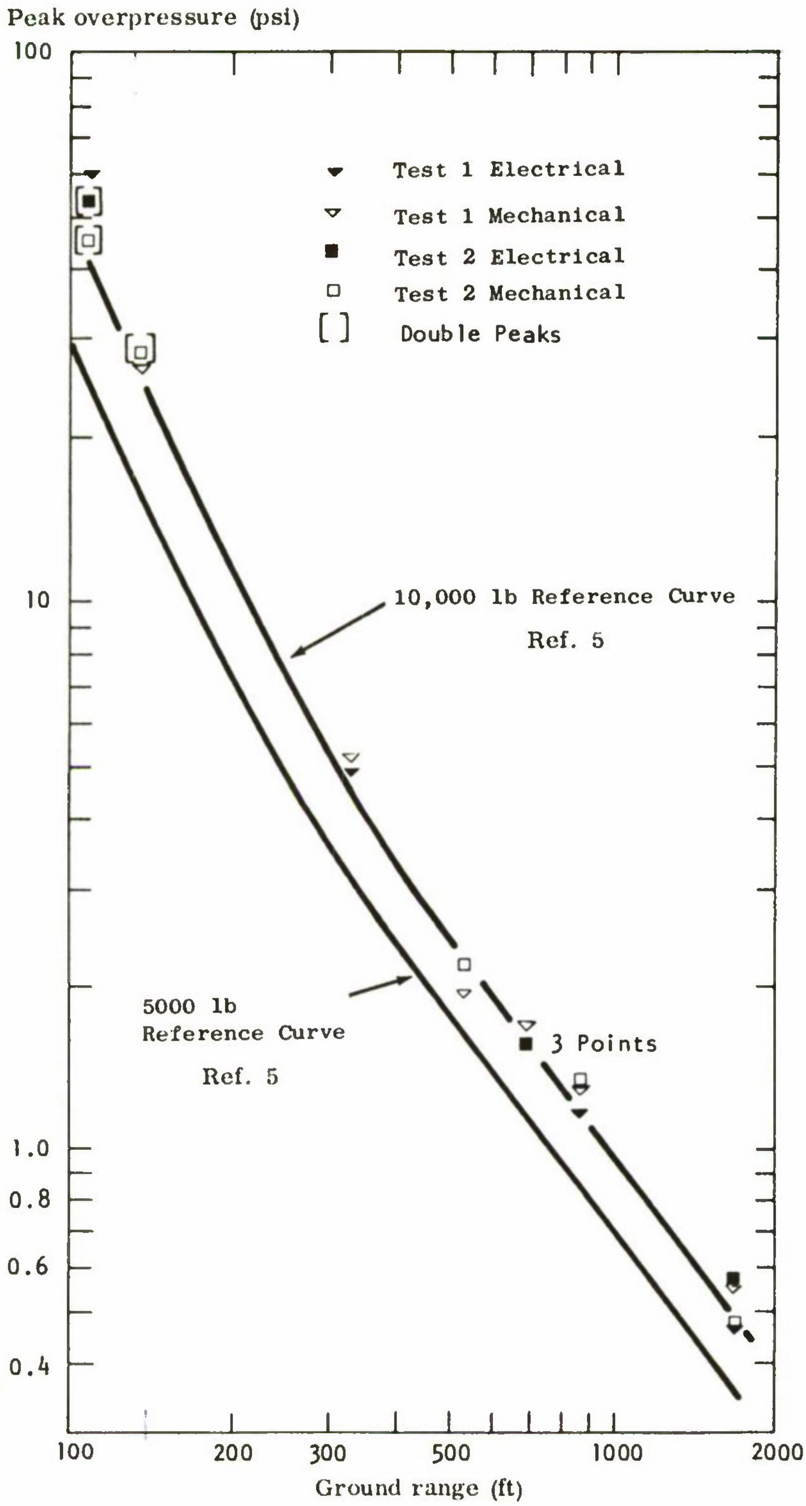

FIG. 23. Peak Overpressure Versus Distance, Unbarricaded Leg (B), Tests 1 and 2.

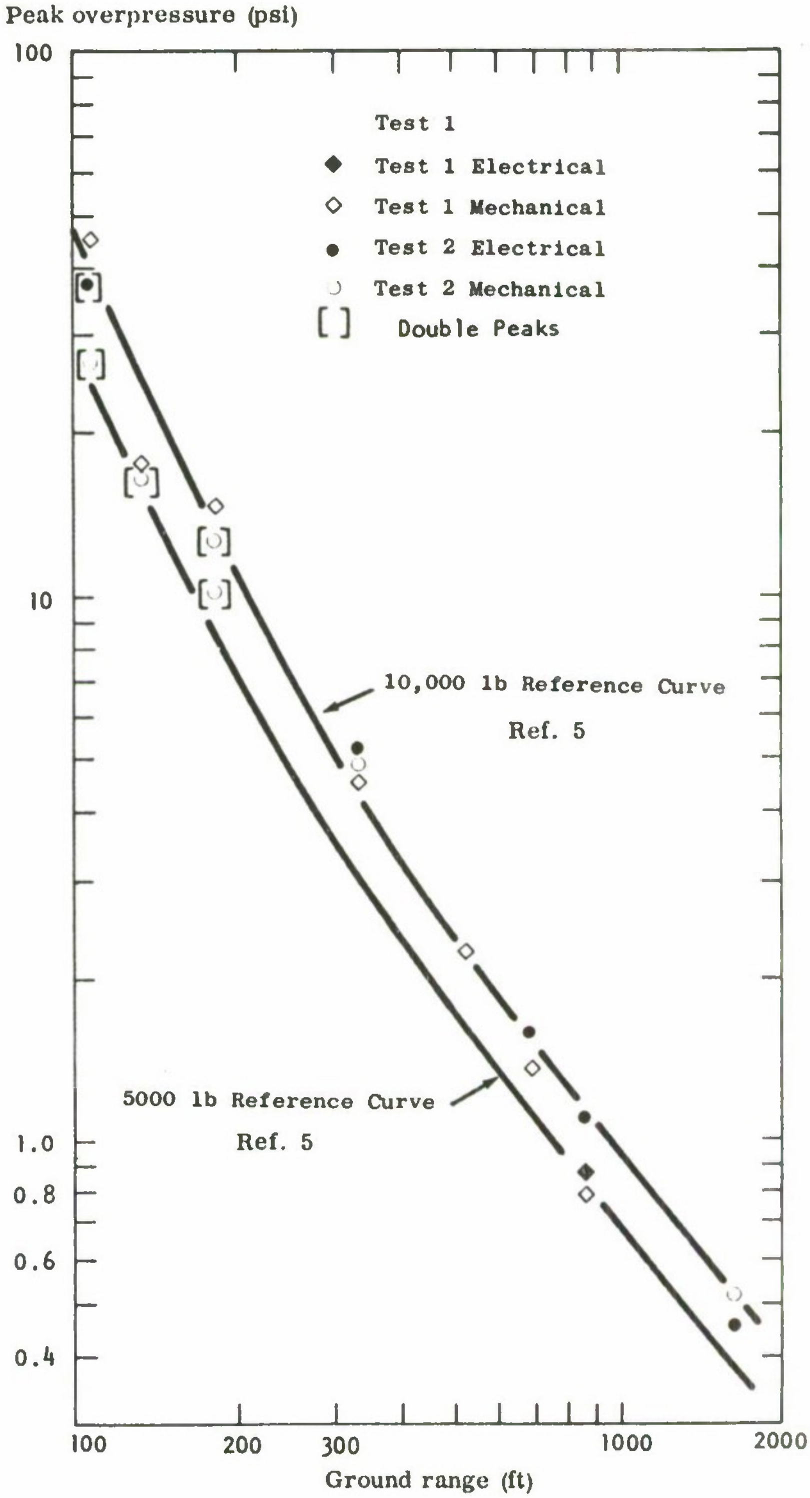

FIG. 24. Peak Overpressure Versus Distance, Barricaded Leg (A), Tests 1 and 2.

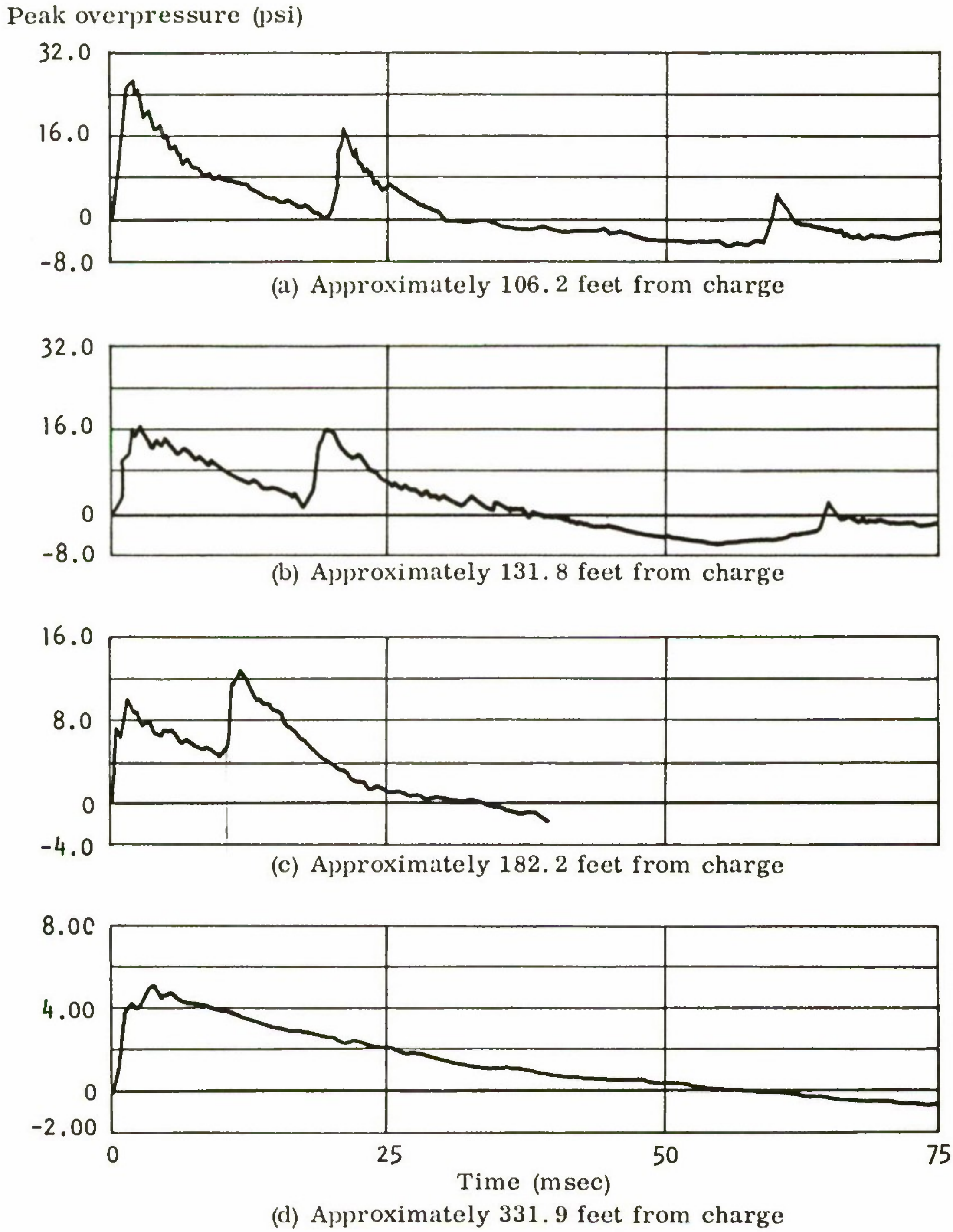

FIG. 25. Gage Recordings on Barricaded Leg (A), Test No. 2.

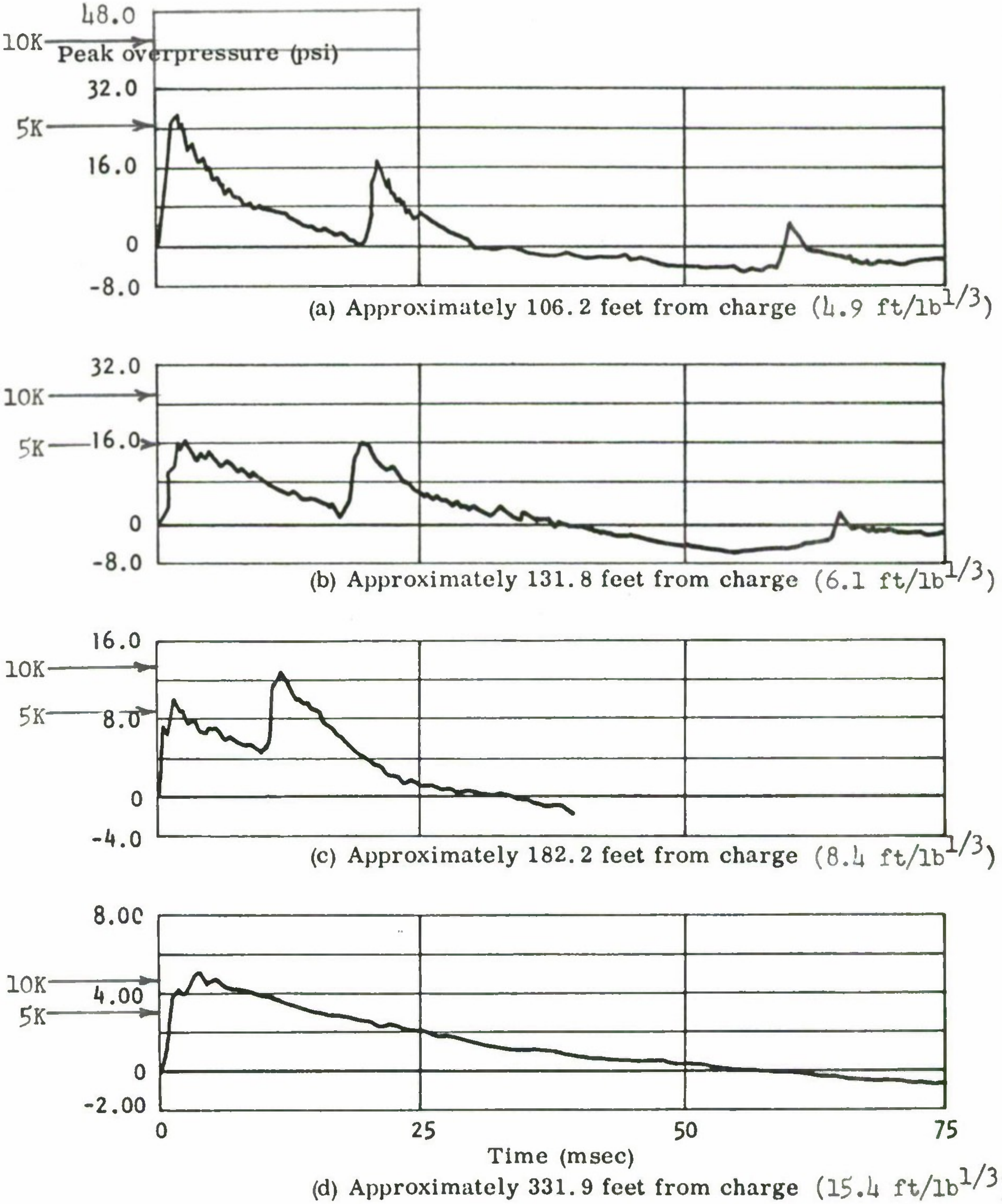

FIG. 25. Gage Recordings on Barricaded Leg (A), Test No. 2.

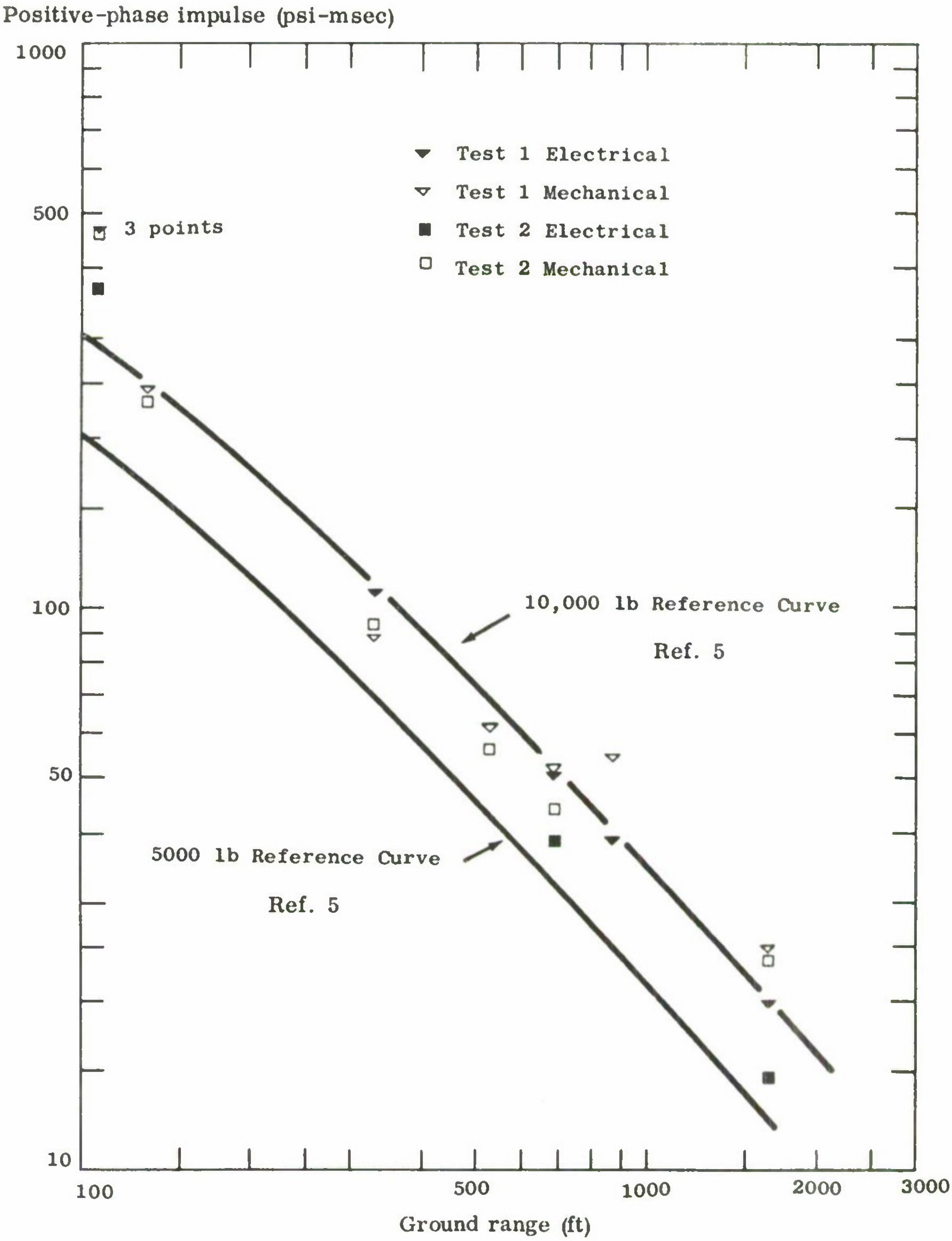

FIG. 26. Positive-Phase Impulse Versus Distance, Unbarricaded Leg (B), Tests 1 and 2.

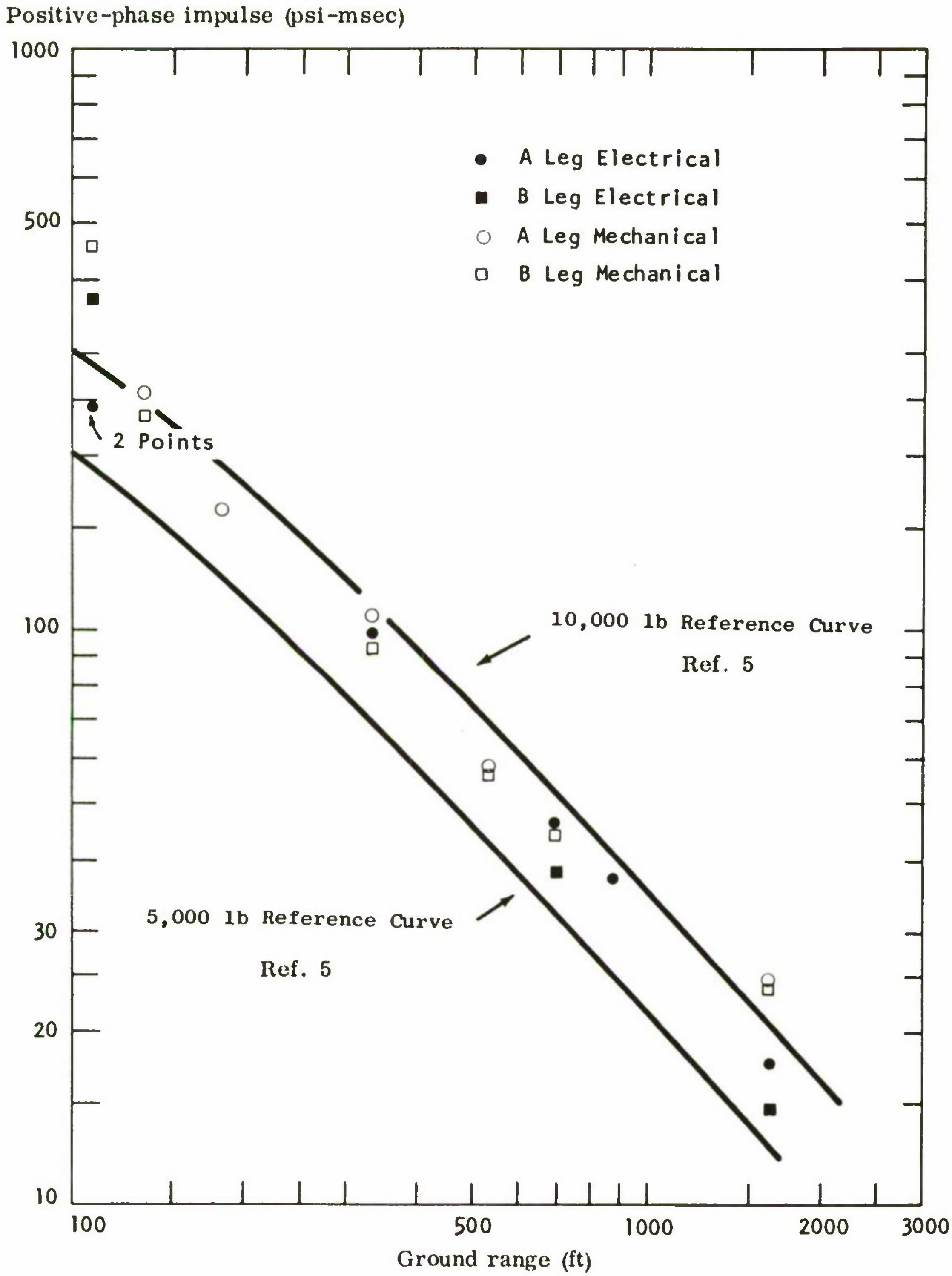

FIG. 27. Positive-Phase Impulse Versus Distance, Barricaded and Unbarricaded Legs, Test No. 2.

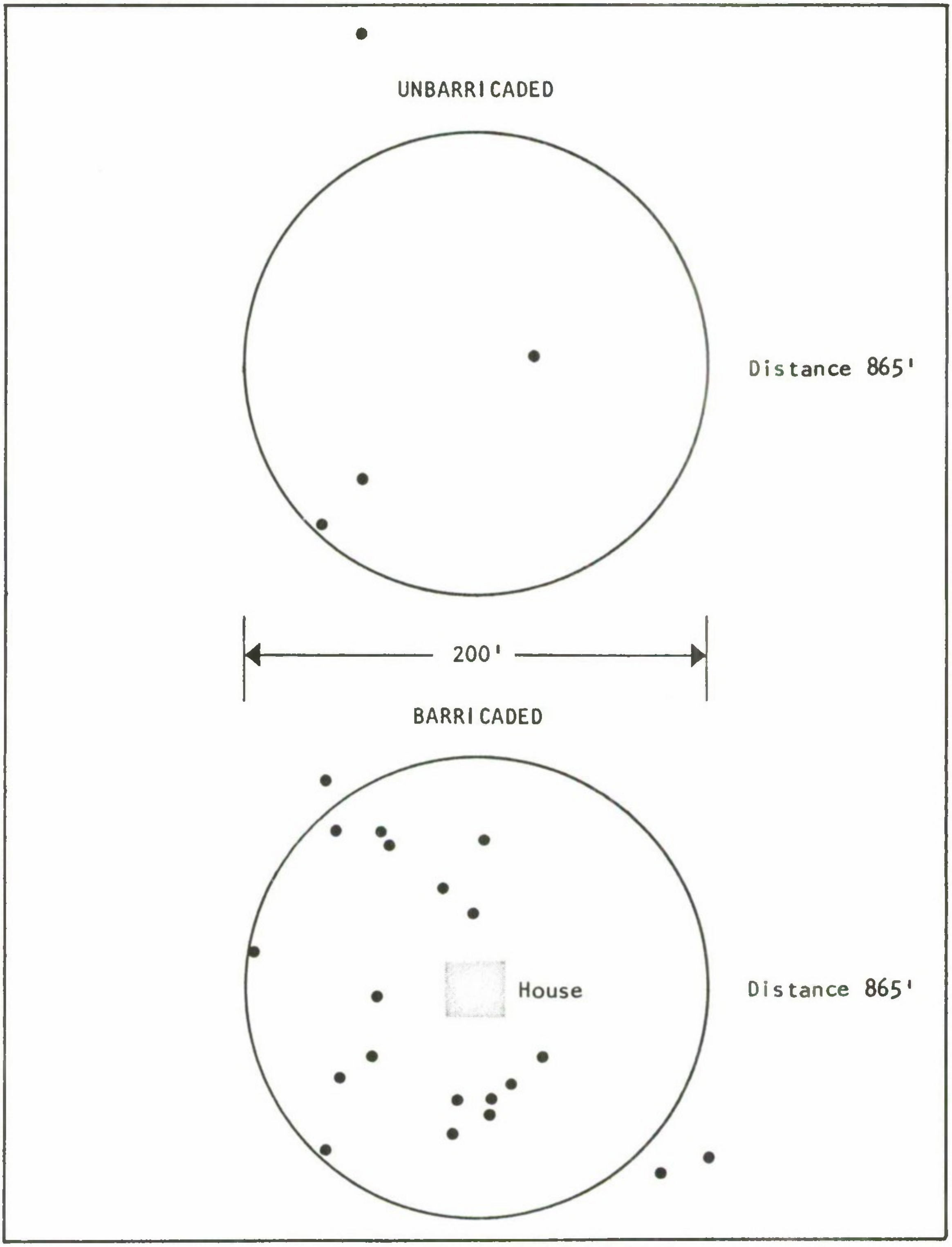

FIG. 28. Search Areas Showing Fragments Found After Test No. 1.

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13. ABSTRACT

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Based on test results, there is no significant difference in the damage to be expected from the detonation of a fixed weight of explosives at the regulation distance from a barricaded inhabited building, either as a single charge or as two equal charges detonated 20 msec apart. Gage lines on opposite sides of the detonation did not register any significant difference between air blast parameters on the barricaded versus the unbarricaded side.

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